COSMIC BACKGROUND BY MARCIA BARTUSIAK

Curiouser and Curiouser

Happy anniversary, white dwarf star!

One hundred fifty years ago, in 1862, the first hint arrived that the stellar universe was far stranger than anyone imagined—or could imagine. It came with the knowledge that a faint companion slowly circles Sirius, the brightest star in the nighttime sky.

Astronomers at the time didn't recognize what they had uncovered. It would take decades—until the 1910s—for them to fully realize that Sirius B, as the tiny companion came to be known, was a star like no other seen before. Once its nature was revealed, though, it didn't take long for theorists to conceive of other bizarre creatures that might be residing in the stellar zoo.

The story begins, not in 1862, but two decades earlier. For a number of years, the noted German astronomer Friedrich Wilhelm Bessel, director of the Königsberg Observatory, had been going through old stellar catalogs, as well as making his own measurements, to track how the stars Sirius and Procyon were moving across the celestial sky over time. By 1844 he had enough data to announce that Sirius and Procyon weren't traveling smoothly, as expected; instead, each star displayed a slight but distinct wobble—up and down, up and down. With great cleverness, Bessel deduced that each star's quivering walk meant it was being pulled on by a dark, invisible companion circling it. Sirius's companion, he estimated, completed one orbit every fifty years.

Bessel was clearly excited by his find; in his communication to Great Britain's Royal Astronomical Society he wrote, "The subject . . . seems to me so important for the whole of practical astronomy, that I think it worthy of having your attention directed to it."

Astronomers did take notice, and some tried to discern Sirius's companion through their telescopes. Unfortunately, at the time Bessel reported his discovery, Sirius B was at its closest to gleaming Sirius, from the point of view of an observer on Earth, and thus lost in the glare. But even years later, no one was successful in spotting the companion.

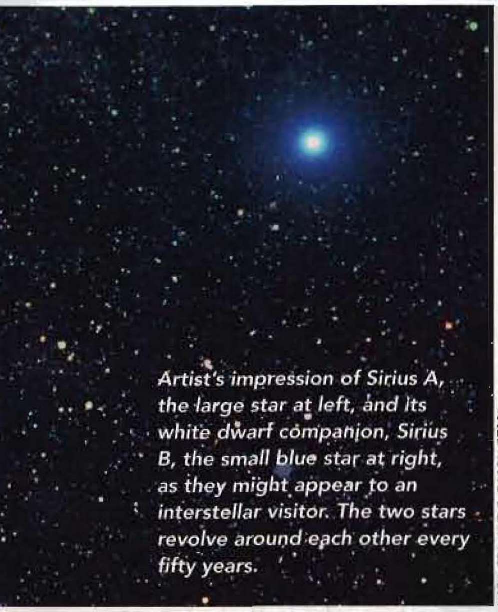
That all changed on January 31, 1862. That night in Cambridgeport, Massachusetts, Alvan Clark, the best telescope manufacturer in the United States, and his younger son, Alvan Graham Clark, were testing the optics for a new refractor they had been building for the University of Mississippi. It was going to be the biggest refracting telescope in the world. Looking at notable stars to carry out a color test of their 18.5-inch lens, the son observed a faint star very close to Sirius.

This momentous sighting might have gone unrecorded. But fortunately, the father was an avid double-star observer and possibly encouraged his son to report the discovery to the nearby Harvard College Observatory. In fact, according to historian Barbara Welther, rather than its being an accidental discovery, as long asserted in astronomy books, "there might have been a [prearranged] connection between the elder Clark and someone at Harvard" to look for Sirius's companion.

Whatever the case, George Bond, the observatory's director, confirmed the find a week later, and he soon wrote up two papers, one submitted to a German journal of astronomy, the other to the *American Journal of Science*. One question was uppermost on Bond's mind: "It remains to be seen," he wrote, "whether this will prove to be the hitherto invisible body disturbing the motions of Sirius." The newfound star seemed to be in the right place to explain the direction of Sirius's wavelike motions, but its luminosity was extremely feeble—so dim, in fact, that it suggested at the time a star too small to have enough mass to account for the wobble. Here was the first clue to Sirius B's uniqueness.

For revealing Sirius's dark companion, Alvan Graham Clark in 1862 garnered the prestigious Lalande Prize, given by the French Academy of Sciences for the year's most outstanding achievement. As astronomers around the globe continued over the years to observe the orbital dance of Sirius and its partner, they eventually determined that the companion was hefty enough (a solar mass) to pull on Sirius, though with a light output less than a hundredth of our Sun's. But no one worried about this disparity. They just figured it was a sunlike star cooling off at the end of its life.

At this point, no one had yet secured a spectrum of the light emanating from Sirius B, a difficult task owing to the overwhelming brightness of the binary's primary star. Astronomers assumed it must be yellow or red, like other dim and cooler



Artist's impression of Sirius A, the large star at left, and its white dwarf companion, Sirius B, the small blue star at right, as they might appear to an interstellar visitor. The two stars revolve around each other every fifty years.

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stars. Astronomy had a general rule at the time: the hotter the star, the brighter. The brightest stars' colors were white, blue-white, or blue.

But in 1910, Princeton astronomer Henry Norris Russell noticed something that cast doubt on that rule. On a Harvard Observatory photographic plate, a faint companion of the star 40 Eridani—a companion known since 1789—was labeled as blue-white. Russell doubted that such a classification could be correct, but in 1914, Walter Adams at the Mount Wilson Observatory in California confirmed the spectrum. How could a star be white-hot, yet dim? "I was flabbergasted," recalled Russell. "I was really baffled trying to make out what it meant." Then, in 1915, Adams determined that Sirius's faint companion, too, displayed the spectral features of a blazing blue-white star.

Soon theorists, such as the British astrophysicist Arthur S. Eddington, figured out what was going on. If a star is both white and hotter than our Sun, it must be emitting more light over each square inch of its surface. But since Sirius B is so faint, that could only mean it had less surface area than our Sun—in other words, it is far smaller, roughly the size of the Earth. Such stars came to be called "white dwarfs."

But how does a Sun's worth of mass get squeezed into such a tiny volume? As Eddington later remarked mischievously,

> The message of the companion of Sirius when it was decoded ran: "I am composed of material 3,000 times denser than anything you have ever come across; a ton of my material would be a little nugget that you could put in a matchbox." What reply can one make to such a message? The reply which most of us made . . . was—"Shut up. Don't talk nonsense."

It took quantum mechanics, under development in the 1920s, to solve the puzzle. By 1926 British theorist Ralph Fowler finally figured out that temperatures inside the compact dwarf star become so extreme that all its atomic nuclei, like droves of little marbles, are packed into the smallest volume possible, while its free electrons generate an internal energy and pressure that keeps it from collapsing even further. This creates an ultradense material impossible to assemble on Earth. Astronomers later learned that this is the end stage for a star like our Sun. The white dwarf is the luminous stellar core left behind after the star runs out of fuel and releases its gaseous outer envelope into space. Such will be our Sun's fate some 5 billion years from now.

The discovery of the extremely dense white dwarf star turned out to be only the first volley in a startling stellar revolution. By the 1930s, working with the new laws of both quantum mechanics and relativity, theorists were astonished (and disturbed) to find that dying stars might face even stranger fates, if they had enough mass. Discovery of the white dwarf had opened up a whole can of cosmic worms.

In the early 1930s a young man named Subrahmanyan Chandrasekhar calculated that if the mass of a white dwarf passes beyond a certain limit (now known to be 1.4 solar masses), it will collapse, its radius approaching zero as the star is overcome by the extreme pressure of gravity. What happens to the star? Chandrasekhar didn't know. All he could say for sure was that a "star of large mass . . . cannot pass into the white-dwarf stage, and one is left speculating on other possibilities."

The great Eddington declared that "there should be a law of nature to prevent a star from behaving in this absurd way!" But, with the discovery of a new atomic particle—the neutron—in 1932, others ventured that the star might end up as a relatively tiny ball of neutrons, not much wider than a city.

J. Robert Oppenheimer, who went on to become the father of the atom bomb, briefly dabbled in the subject, joining with two of his graduate students to ponder a neutron star's range of stable masses. And in these deliberations he and his student Hartland S. Snyder in 1939 calculated that past a certain threshold of mass, the neutron star itself would not endure but instead face "continued gravitational contraction." The neutrons could no longer serve as an adequate brake against collapse. Oppenheimer and Snyder found that the last light waves to flee get so drawn out by the enormous pull of gravity that the rays become invisible, and the star vanishes from sight. The star literally closes itself off from the rest of the universe. "Only its gravitational field persists," reported Oppenheimer and Snyder. By 1968, astronomers began calling these objects "black holes."

Today astronomers recognize that galaxies are peppered with both black holes and rapidly spinning neutron stars (we know them as pulsars). And our understanding of such zany stellar outcomes commenced, in a way, with the discovery of Sirius's faint companion, first spotted (maybe by accident, maybe not) 150 years ago.

Happy anniversary, white dwarf star!

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